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EFFECT OF CLIMATE CHANGE ON GRAPEVINES PHENOLOGICAL STAGES AND YIELD UNDER ARID ENVIRONMENT

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ABSTRACT

Climate change is a dramatic crisis that has left severe impacts on the agricultural sector and especially on viticulture. Phenological sets over 41 years and annual climatic anomalies 'data over the same years' intervals were procured. An earliness in Al Ahsa region, the first signs of climate change were detected starting 1997, where annual precipitable water and temperature anomalies were the most important climate influencers all phenological events occurred for the varieties White and Red, from the beginning of budburst until harvest. Moreover, the yield of both varieties was slightly reduced between 1997 and 2019 in comparison with the interval of years 1979-1996. Beginning of budburst, budburst, 2-3 leaves unfolded and visible inflorescence were positively correlated with the annual wind speed anomaly. Beginning of flowering, full flowering, beginning of fruit set, full veraison, and harvest were positively with the annual total cloud cover anomaly and annual total precipitation anomaly. In addition, the full fruit set and beginning of veraison were positively correlated with annual wind speed anomaly, and negatively correlated with annual precipitable water anomaly.

Yield was positively correlated with annual total precipitation anomaly and annual total cloud cover anomaly. Results suggest the adoption of a drip irrigation system in Al Ahsa vineyards that would overcome the low water availability in hot summers and reduce soil salinity, one of the biggest issues facing Gulf countries.

Keywords **:** Climate Change, Viticulture, Phenology, Yield, Arid Environment

Introduction

Climate change arises after more than ten thousand years of relative stability. The extent of its effects on individual regions will vary over time, with the ability of different social and environmental systems to mitigate or adapt to this issue. According to the Intergovernmental Panel on Climate Change (IPCC, 2013) increases in global mean temperature of less than 1 to 3 degrees Celsius, starting from the year 1990 will produce beneficial impacts in some regions and 40 harmful ones in others.

Projections suggest that the rate of increase in agricultural production will slow over the next few decades, and it may start to decline after about 2050 Verner *et al.* (2012). In this context, Arab countries' agricultural development will be most likely affected, either positively or negatively, by climate change. Generally, most viticulture regions are located worldwide between latitudes of 40° and 50°N in northern hemisphere and between latitudes of 30° and 40°S in the southern hemisphere called as temperate climatic belt Iland *et al.* (2009). Climate is an important forcing factor on grapevine (*Vitisvini fera* L.) physiological development Keller (2010), vegetative growth Van Leeuwen *et al.* (2004), phenology Costa *et al.* (2019), and consequently production. Climatic factors also determine the geographical location of vineyards Fraga and *et al.* (2019). Moreover, the variability in weather parameters, such as air temperature, precipitation, and solar radiation, leads to annual changes in productivity Jones and Davis (2000); Fraga and Santos (2017). In addition, the duration of each phenological stage differs according to each grapevine variety, which is generally linked to the thermal conditions of each region Mandelli *et al.* (2005). It has to be acknowledged that climate change may not necessary affect negatively vineyards yields. Most of climatic change reports focused on the Mediterranean region. While lower grape yields are observed in several Mediterranean countries such as Algeria, Greece, Portugal, Morocco, Turkey, and Egypt, other countries like Spain, Bulgaria, and Italy showed to have positive or negative yield changes on equal shares of their respective vineyard areas. On the other hand, some yield increases are expected in Germany and Hungary Ponti *et al.* (2018).

Arab countries enclose a wide number of grape varieties that are used for direct consumption Mohasseb *et al.* (2020) and showed to be affected by climate change Ghantous *et al.* (2018). The Kingdom of Saudi Arabia lies between 15.2° and 32.6° North and 34.1° and 55.5° east. Its climate is generally mild in the winter, dry, and hot in the summer suitable for grape cultivation. The latter is the second most important fruit in Saudi Arabia on an economical scale Fahmi *et* *al*.,(2012). It was reported that the hectar age of planted fruit crops in Saudi Arabia has increased by 13% between 2001 and 2005, where grapes represent 8.5% of this area yielding around 132 thousand tons Al-Qurashi(2010). Locals reported that Al-Sulaybiya, a region of Saudi Arabia, supplies more than 20,000 tons of different varieties of grapes all over the country. Al Ahsa region, located in the east of the Kingdom, is well known for its traditional original and high quality white and red grapes locally known as "Hassaoui". However, the global change issue may affect this agricultural heritage. No previous studies reported the effect of climate change on grapevine cultivation in the Gulf region, and especially in the Kingdom of Saudi Arabia. Purposely, the phenological traits and production of white and red Hassaoui varieties were studied all over 41 years in order to detect whether their performance is affected or not by climate change, and if yes, whether it was a positive or a negative one.

Materials and Methods

Climatic Events

The European Centre for Medium-Range Weather Forecasts (ECMWF ERA5) provided the annual climate data. The climatic annual parameters (precipitable water anomaly (Ann PWA), temperature anomaly (Ann TA), wind speed anomaly (Ann WSA), total precipitation anomaly (Ann TPA), total cloud cover anomaly (Ann TCCA)) were grouped for an adequate interpretation of the climate effect on the different phonological stages of the grapevines.

Vineyards Description

Vineyards of White and Red Hassaoui are located in Al Ahsa province, eastern Saudi Arabia Kingdom at an altitude of 100-150 meters above sea level. In this province, summers are long, sweltering, and arid; the winters are cool and dry; and it is mostly clear year round. Sunlight lasts in average between 10.3 hours to 13.4 hours, with a mean fall in temperature of around 10-15°C between day and night. Vineyards of White and Red Hassaoui cover a surface of 20200 m^2 and 23100 m^2, respectively. In both types of vineyards, the distance of plantation was of 2.5 m × 1.25 m. White and Red Hassaoui vines were pruned back to spurs about a hand's width apart, each with 2 buds.

Data Collection

Data of the studied vineyards was obtained from the Saudi Ministry of Environment, Water & Agriculture. Studied phenological events and yield were monitored by local farmers under the continuous supervision of governmental inspectors. The study of different events was based on selected and marked rows from each vineyard in order to increase the diversity and to approve the accuracy and validity of each occurring phenological event. In addition, ten grapevines from each row were chosen randomly. Selected rows and grapevines were marked by a strip, for an easier identification, thus an easier data collection.

Phenological Events

The leaf fall stage was used as reference day to evaluate the changes in phenological events. Phenological events (stages), including beginning budburst (stage C), 2-3 leaves unfolded (stage E), visible inflorescence (stage F), beginning of flowering (stage I1), beginning of fruit set (stage J1), and beginning of veraison (stage M1) were recorded once 10% of the total number of selected vines reached the relative stage. The date of budburst (stage D) was recorded when green shoot tips were visible in all sampled vines. The dates of full flowering (stage I2), full fruit set (stage J2), full veraison (stage M2), and harvest (stage O) were determined when 80% of selected plants reached the relative stage. All stages were expressed in days.

In addition, the intervals of time (expressed in days) between the different phenological stages were determined as follows: budburst to flowering (P1), budburst to fruit set (P2), budburst to veraison (P3), beginning of flowering to veraison (P4), full flowering to veraison (P5), beginning of veraison to full veraison (P6), beginning of veraison to harvest (P7), full veraison to harvest (P8), beginning of flowering to harvest (P9), full flowering to harvest (P10), and budburst to harvest (P11).

Quantitative Traits

Production was evaluated in terms of yield (recorded per vine and then expressed as kg/ha).

Statistical Analysis

Analysis was divided into general and specific tests reflecting the effects of "year", and "varieties" on vine performance. Cluster analysis was performed using SPSS program in order to divide years (from 1979 to 2019) into two clusters based on climatic factors anomalies. In other terms, each cluster includes a series of years having more or less similar or comparable means of the already listed climatic factors anomalies. The contribution of each climatic factor in the cluster analysis was determined using the factor analysis option provided by SPSS program. The aim of this test was to detect possible variability in climatic conditions in the growing regions of the selected table grapes during the last 41 years.

Second, ANOVA test was performed to detect the separate effect of annual climatic anomalies, variety, and year on phenological events and yield in both types of grapevines. Then, the combined effects of different factors were studied on phenological events and yield of the selected grapevines.

Phenological stages were divided into three sets based on thegrowth state of grapevines. Set 1 including stage C (beginning of budburst), stage D (budburst), stage E (2-3 leaves unfolded) and stage F (visible inflorescence). Set 2 including stage I1 (beginning of flowering), stage I2 (full flowering), stage J1 (beginning of fruit set) and stage J2 (full fruit set). Set 3 including stage M1 (beginning of veraison), stage M2 (full veraison) and stage O (harvest). The intervals of time between the different phenological stages were divided into two sets. Set 4 including P1: budburst to flowering, P2: budburst to fruit set, P3: budburst to veraison, P4: beginning flowering to veraison, and P5: full flowering to veraison. Set 5 including P6: beginning of veraison to full veraison, P7: beginning veraison to harvest, P8: full veraison to harvest, P9: beginning flowering to harvest, P10: full flowering to harvest, and P11: budburst to harvest.

Principal component analysis (PCA) was also performed to detect the type of correlations between phenological events and yield on one hand and climatic anomalies on the other one. A Pvalue<0.05 was adopted in all statistical tests.

Results and Discussion

Cluster Analysis

The two-step cluster analysis (Table 1) showed two identifiable year clusters based on the climatic factors anomalies all over 41 years. The first cluster grouped the years between 1979 and 1996 (both included), while the second one grouped the remaining years from 1997 till 2019 (both included) showing a clear climate change in Al Ahsa region in the last two decades.

Weather and climate factors are the keys that govern viticulture Keller (2010). Effectively, air temperature may be the biggest influencer on vines' vegetative cycle, better described by the term morphological stages (events) Malheiro *et al*. (2013). The same authors reported that precipitation and radiation are also important, though to a lesser extent. In the current study, the performed factor analysis showed the relative low importance of the annual climate predictors: total precipitation anomaly and total cloud cover anomaly. After a period of chilling temperatures in winter for breaking dormancy, the growing season begins with budburst in early spring. A cumulative effect of temperatures above a threshold of 10°C is the classical thermal requirement for this event to take place Winkler *et al*. (1974). When the vines lose their leaves, mild temperatures and considerable precipitation totals during the dormant period are critical for the next growing season, particularly in Mediterranean regions Magalhães(2008). During flowering, veraison, and harvest warm temperatures are required for balanced crop yield Jones and Davis(2000).

The increase in temperature anomaly observed in the last 41 years was coupled with a similar decrease in total cloud cover anomaly. Most studies that addressed the links between climate change conditions and vine phenology have reported earlier occurrence of phenological events, shorter phenological intervals, and warmer grape maturation periods, suggesting that these changes are mostly likely due to the temperature rise Malheiro *et al*. (2013). Annual temperature anomaly had a significant effect on the stages of beginning of budburst, budburst; 2-3 leaves unfolded, visible inflorescence, beginning of veraison, full veraison, and harvest. The beginning of flowering was hastened in the last five years in comparison with years grouped in the first cluster. Also, the beginning of veraison as well as harvest was hastened in comparison with the same range of years. This could be explained by the increasing annual temperature anomaly. According to Keller (2010) an upward shift in temperature will change the growing season thereby reducing the days to beginning of flowering, veraison, and harvest confirming our results. Furthermore, the decreasing annual total cloud cover anomaly in the last five could explain the earliness in all grapevines' development stages. Webb *et al.* (2012) confirmed also earlier that high temperature and solar radiation cause earliness in the consecutive plant development stages with a shorter duration between them. The reducing annual total cloud cover anomaly was observed to be slightly correlated with the stages between beginning of budburst and visible inflorescence (stages C, D, E, and F). Pearce and Coombe (2004); Keller and Tarara (2010) noted that higher temperatures during the latter part of winter will accelerate budburst date, and stimulated vegetative growth during the growing season. Pouget (1981) have demonstrated that high temperatures during budburst reduce flower numbers per inflorescence. Temperature is a key environmental factor that affects inflorescence development, which begins at budburst (May 2004). Annual temperature anomaly has effectively affected the interval between budburst and veraison. Shortening of the intervals between flowering to veraison and veraison to harvest are generally linked to better climatic conditions for growth and development Jones and Davis (2000). In fact, annual temperature anomaly has also hastened harvest. It was mainly observed during the last five years. Warming trends during the growing season led to acceleration in harvest Webb *et al*. (2012); Jones (2013).

Table 1 : Cluster analysis based on the climatic factors anomalies

Cluster 1	Cluster 2
1979	1997
1980	1998
1981	1999
1982	2000
1983	2001
1984	2002
1985	2003
1986	2004
1987	2005
1988	2006
1989	2007
1990	2008
1991	2009
1992	2010
1993	2011
1994	2012
1995	2013
1996	2013
	2014
	2015
	2016
	2017
	2018
	2019

Both White and Red Hassaoui varieties were harvested earlier by 34-35 days in the last five years in comparison with all previous years mainly between 1979 and 1996. Furthermore, the impacts of climatic change in Al Ahsa region are likely to be generally negative in terms of harvested yields of both White and Red Hassaoui varieties. Grape production is sensitive to heat influences, especially at flowering and ripening stages Greer and Weston (2010). Fidelibus (2018) detected that spring heat waves can reduce fruit set, and thus decrease yield. In the current study, a strong positive correlation between annual wind speed anomaly and fruit set was observed. As an increasing annual temperature anomaly was detected, this suggests a higher air temperature, and thus, explains the medium to low yields obtained mainly in the last five years.

Factor Analysis

The factor analysis (Table 2) showed that annual perceptible water anomaly first, and temperature anomaly secondly was the main and most influencing predictors, followed by annual wind speed anomaly.

Table 2 : Contribution level of each predictor

Predictor	Importance
Ann PWA (kg m^{-2})	2.18
Ann TA (°C)	1.24
Ann WSA (m s^{-1})	0.98
Ann TPA (m)	0.43
Ann TCCA (%)	0.16

Ann PWA: annual precipitable water anomaly, Ann TA: annual temperature anomaly, Ann WSA: annual wind speed anomaly, Ann TPA: annual total precipitation anomaly, Ann TCCA: annual total cloud cover anomaly.

The overall earliness in all phenological stages of both White and Red Hassaoui varieties suggests big changes in the whole management schedule of Al Ahsa vineyards. The phenological characteristics of individual grapevine varieties as well as their responses to climate are of utmost importance for activity planning and decision making in viticulture. On the other hand, a drastic decrease in the annual total precipitation anomaly occurred in Al Ahsa region mainly in the last five years. Changes in grapevine water status at critical phenological stages have a direct effect on grape composition and quality attributes by influencing vegetative growth, yield, and fruit metabolism Ezzhaouani *et al.* (2007).

Moreover, during the early stages of vegetative growth, strong winds play a major role in determining the production of grapevines. It can break off the new shoots, delaying and even reducing the amount of flowering. In the current study, soft winds and reduced annual wind speed anomaly were detected resulting in accelerated phenological events. As the berries proceed through veraison and into the maturation stage, high winds can be very effective at desiccating the fruit and can result in lower quality Jones (2015).

ANOVA Test

The separate and combined effects of different factors on phenological stages and yield of white and red Hassaoui grapevines were studied. The separate effects of “Variety White Hassaoui” and “Variety Red Hassaoui” (Table 3) were significant in terms of the stages C, E, and F in set 1, I1, I2 and J2 in set 2, O in set 3 and yield. The separate effect of the factor “Year” was significant in terms of all phenological sets and yield except stages J1 in set 2 and M2 in set 3. Moreover, the combined effects of “Variety White Hassaoui*Year” and “Variety Red Hassaoui*Year” were significant on yield and all phenological sets except stages J1 in set 2 and M2 in set 3. Additionally, the separate effect of “annual precipitable water anomaly (Ann PWA)” was only significant on the stages I1 in set 2 and O in set 3. “Annual temperature anomaly (Ann TA)” and “annual wind speed anomaly (Ann WSA)” were significant in the first three phenological sets and yield; while, “annual total precipitation anomaly (Ann TPA)” and “annual total cloud cover anomaly (Ann TCCA)” were only significant in terms of the latter.

Table 3 : Separate and combined effects of the variety, year, and climate factors on sets 1,2 and 3 phenological events (P_{value}<0.05)

	P_{value} of stage C	P_{value} of stage D	P_{value} of stage E	P_{value} of stage F	P_{value} of stage I1	P_{value} of stage I2	P_{value} of stage J1	P_{value} of stage J2	P_{value} of stage M1	P_{value} of stage M2	P_{value} of stage O	P_{value} of yield
Variety White Hassaoui	0.00	0.85	0.00	0.00	0.00	0.00	0.34	0.01	0.85	0.28	0.00	0.00
Variety Red Hassaoui	0.00	0.37	0.00	0.00	0.00	0.00	0.27	0.03	0.58	0.32	0.00	0.00
Year	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.67	0.00	0.00
Variety White Hassaoui*Year	0.00	0.00	0.00	0.00	0.49	0.00	0.49	0.00	0.00	0.47	0.00	0.00
Variety Red Hassaoui*Year	0.00	0.00	0.00	0.00	0.52	0.00	0.36	0.00	0.00	0.21	0.00	0.00
Ann PWA	0.09	0.25	0.24	0.09	0.01	0.09	0.09	0.17	0.30	0.09	0.01	0.90
Ann TA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95
Ann WSA	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.04
Ann TPA	0.28	0.26	0.24	0.28	0.19	0.28	0.28	0.33	0.41	0.28	0.14	0.00
Ann TCCA	0.08	0.08	0.08	0.08	0.09	0.08	0.08	0.09	0.09	0.08	0.08	0.01

Stage C: beginning of budburst, stage D: budburst, stage E: 2-3 leaves unfolded, stage F: visible inflorescence, Stage I1: beginning of flowering, stage I2: full flowering, stage J1: beginning fruit set, stage J2: full fruit set, Stage M1: beginning of veraison, stage M2: full veraison, stage O: harvest,Ann PWA: annual precipitable water anomaly, Ann TA: annual temperature anomaly, Ann WSA: annual wind speed anomaly, Ann TPA: annual total precipitation anomaly, Ann TCCA: annual total cloud cover anomaly.

The separate effects of “Variety White Hassaoui” and “Variety Red Hassaoui” were significant on the interval of time from budburst to flowering (P1), beginning of flowering to veraison (P4), and full flowering to veraison (P5) and on all set 5 intervals (Table 4). In addition, the combined effects of “Variety White Hassaoui*Year” and “Variety Red Hassaoui*Year” showed a significance on all set 4 intervals, except budburst to veraison (P3), and on all set 5 intervals. All set 4 and set 5 intervals were significantly affected by the factor ‘Year’. Annual temperature, wind speed and total precipitation anomalies had significance only in terms of budburst to veraison (P3).

Results in Table 5 showed that in the last five years (from 2015 till 2019), set 1 phenological events: beginning of budburst (stage C), budburst (stage D), 2-3 leaves unfolded (stage E) and visible inflorescence (stage F) were hastened by a mean of 30-33 days, 32 days, 32-33 days and 30-32 days, respectively in comparison with the mean values representing years grouped in the first cluster (from 1979 till 1996). Set 2 phenological events: beginning of flowering (stage I1), full flowering (stage I2), beginning of fruit set (stage J1) and full fruit set (stage J2) were also hastened by 31-34 days, 30-32 days, 30-32 days and 30 days, respectively in comparison with the mean values related to the same range of years.

Table 4 : Separate and combined effects of variety, year, and climate factors on intervals between phenological events

	P_{value} of P1	P_{value} of P2	$P_{value}$of P3	P_{value} of P4	P_{value} of P5	P_{value} of P6	P_{value} of P7	P_{value} of P8	P_{value} of P9	P_{value} of P10	P_{value} of P11
Variety White Hassaoui	0.00	0.06	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Variety Red Hassaoui	0.00	0.07	0.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Variety White Hassaoui*Year	0.00	0.01	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Variety Red Hassaoui*Year	0.00	0.02	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ann PWA	0.81	0.92	0.54	0.99	0.99	0.99	0.97	0.96	0.99	1.00	1.00
Ann TA	0.06	0.52	0.00	0.68	0.95	0.31	0.84	0.50	0.98	1.00	1.00
Ann WSA	0.31	0.95	0.02	0.92	0.72	0.94	0.89	0.72	0.99	1.00	1.00
Ann TPA	0.49	0.36	0.02	0.97	0.87	0.53	0.42	0.90	0.80	0.92	0.99
Ann TCCA	0.74	0.95	0.38	0.99	1.00	0.99	0.99	0.99	0.99	1.00	1.00

P1: budburst to flowering, P2: budburst to fruit set, P3: budburst to veraison, P4: beginning of flowering to veraison, P5: full flowering to veraison, P6: beginning of veraison to full veraison, P7: beginning veraison to harvest, P8: full veraison to harvest, P9: beginning flowering to harvest, P10: full flowering to harvest, P11: budburst to harvest, Ann PWA: annual precipitable water anomaly, Ann TA: annual temperature anomaly, Ann WSA: annual wind speed anomaly, Ann TPA: annual total precipitation anomaly, Ann TCCA: annual total cloud cover anomaly.

Also in the last five years, set 3 events: beginning veraison (stage M1), full veraison (stage M2) and harvest (stage O) were earlier by 30-31 days, 30-33 days and 31-32 days, respectively compared to their mean values in the first cluster years. Yield varied widely between the two clusters of years, being the lowest in 2001 (11277.6 kg/ha) and the highest in 1995 (18867.4 kg/ha). The yield of White Hassaoui variety decreased by around 320 kg/ha between 1997 and 2019 in comparison with the mean yield noted between 1979 and 1996.

Results in Table 6 showed that in the last five years (from 2015 till 2019), set 1 phenological events: beginning of budburst (stage C), budburst (stage D), 2-3 leaves unfolded (stage E) and visible inflorescence (stage F) were hastened by 33-35 days, 33-37 days, 32-34 days and 33-35 days, respectively in comparison with the mean values representing years grouped in the first cluster (from 1979 till 1996). Set 2 phenological events: beginning of flowering (stage I1), full flowering (stage I2), beginning of fruit set (stage J1) and full fruit set (stage J2) were also hastened by 33-36 days, 33-36 days, 33 days, and 35 days, respectively in comparison with the mean values obtained in cluster one years. Set 3 phenological events: beginning veraison (stage M1), full veraison (stage M2), and harvest (stage O) showed an earliness in the last five years in comparison with their mean values in the first cluster years by 33-35 days, 33-35 days, and 34-35 days, respectively. Yield varied widely between the two clusters, giving the lowest values in 2001 (11126.17 kg/ha) and 2010 (11154.28 kg/ha), and the highest one in 1995 (18426.84 kg/ha). The mean yield of Red Hassaoui variety decreased by around 317 kg/ha between 1997 and 2019 in comparison with the mean yield noted between 1979 and 1996.

Table 5 : Variation of sets 1, 2, and 3 phenological events of White Hassaoui as affected by year

Year	Stage C (Days)	Stage D (Days)	Stage E (Days)	Stage F (Days)	Stage I1 (Days)	Stage I2 (Days)	Stage J1 (Days)	Stage J2 (Days)	Stage M1 (Days)	Stage M2 (Days)	Stage O (Days)	Yield (kg/ha)
1979	210r	213p	215s	227r	236l	241r	241r	258p	294qr	308pq	323n	12329.5de
1980	202mn	206m	209op	219mn	227j	233mn	233mn	248l	286mn	300mn	314l	13522.3f
1981	203no	206m	208no	220no	230k	234no	234no	250mn	285lm	301mn	317m	11410.4abc
1982	217u	221u	224v	234u	243o	248u	248u	263r	297t	315t	330p	15347.2mn
1983	206q	211o	213r	223q	231k	237q	237q	254o	290o	304o	318m	15921.3o
1984	214st	218s	221u	231st	240n	245st	245st	261q	295rs	312rs	328o	11858.5bcd
1985	215t	218s	220u	232t	240n	246t	246t	261q	296st	313st	328o	11921.7bcd
1986	211r	215r	218t	228r	238m	242r	242r	258p	295rs	309pq	323n	14852.2klm
1987	205pq	208n	211q	222pq	231k	236pq	236pq	253o	289o	303o	318m	13736.8fg
1988	203no	208n	210pq	220no	230k	234no	234no	250mn	286mn	301mn	314l	14127.5ghij
1989	211r	213p	216s	228r	236l	242r	242r	257p	292p	309pq	324n	14624.4jkl
1990	200l	204l	207n	217l	227j	231l	231l	248l	284l	298l	314l	11656abc
1991	202mn	205lm	208no	219mn	228j	233mn	233mn	249lm	286mn	301mn	315l	13934.4fghi
1992	215t	219st	221u	232t	240n	246t	246t	261q	295rs	313st	328o	17150.8q
1993	218u	220tu	223v	235u	244o	249u	249u	265s	300u	316u	330p	14987.2lm
1994	213s	216r	218t	230s	238m	244s	244s	260q	296st	311rs	324n	11355.8ab
1995	204op	208n	211q	221op	231k	235op	235op	251n	287n	302n	317m	18867.4r
1996	211r	213p	216s	228r	236l	242r	242r	257p	293pq	309pq	324n	16474.6p
1997	201lm	205lm	207n	218lm	228j	232lm	232lm	248l	284l	299l	314l	15987.3op
1998	191h	194gh	196ij	208h	218g	222h	222h	239h	275h	289h	304h	14366.5hijk

1999	205pq	209n	211q	222pq	231k	236pq	236pq	253o	289o	303o	317m	11687.9abc
2000	205pq	208n	210pq	222pq	231k	236pq	236pq	253o	289o	303o	317m	12531.2e
2001	196jk	200jk	203lm	213jk	223i	227jk	227jk	244jk	280jk	294jk	309jk	11277.6a
2002	191h	194gh	196ij	208h	218g	222h	222h	239h	275h	289h	304h	11965.2cd
2003	191h	194gh	196ij	208h	218g	222h	222h	239h	275h	289h	304h	16038.9op
2004	195ij	199j	202l	212ij	222i	226ij	226ij	243ij	279ij	293ij	308ij	15064.7lm
2005	186ef	188e	191e	203ef	213e	217ef	217ef	234ef	270ef	284ef	299ef	13983.4fghi
2006	190gh	193g	195hi	207gh	216f	221gh	221gh	238gh	274gh	288gh	303gh	17026.5q
2007	190gh	193g	195hi	207gh	216f	221gh	221gh	238gh	274gh	288gh	303gh	13842.7fgh
2008	197k	201k	204m	214k	222i	228k	228k	245k	281k	295k	310k	11568.7abc
2009	190gh	194gh	197j	207gh	217fg	221gh	221gh	238gh	274gh	288gh	303gh	13844.2fgh
2010	187f	189e	192ef	204f	214e	218f	218f	235f	271f	285f	300f	11357.3ab
2011	194i	197i	199k	211i	220h	225i	225i	242i	278i	292i	307i	14425.0ijk
2012	191h	195h	197j	208h	218g	222h	222h	239h	275h	289h	304h	13956.5fghi
2013	189g	191f	194gh	206g	216f	220g	220g	237g	273g	287g	302g	15622.4no
2014	187f	191f	193fg	204f	213e	218f	218f	235f	271f	285f	300f	11879bcd
2015	180c	183c	185c	197c	207c	211c	211c	228c	264c	278c	293c	14399.5hijk
2016	170a	172a	175a	187a	196a	201a	201a	218a	254a	268a	283a	13684.1fg
2017	177b	179b	182b	194b	204b	208b	208b	225b	261b	275b	290b	15889.4o
2018	183d	186d	188d	200d	209d	214d	214d	231d	267d	281d	296d	12537.68e
2019	185e	189e	191e	202e	210d	216e	216e	233e	269e	283e	298e	14405.9hijk

Stage C: beginning of budburst, stage D: budburst, stage E: 2-3 leaves unfolded, stage F: visible inflorescence, Stage I1: beginning of flowering, stage I2: full flowering, stage J1: beginning fruit set, stage J2: full fruit set, Stage M1: beginning of veraison, stage M2: full veraison, stage O: harvest.

Principle Component Analysis (PCA)

During the last forty one years, phenological events from green showing to visible inflorescence (stages C, D, E, and F) were strongly positively correlated with annual wind speed anomaly (Ann WSA), and slightly positively correlated with annual total precipitation anomaly (Ann TPA) and annual total cloud cover anomaly (Ann TCCA) (Fig. 1). Set 1 phenological events were also strongly negatively correlated with annual precipitable water anomaly (Ann PWA) and annual temperature anomaly (Ann TA). Moreover, yield was strongly positively correlated with Ann TPA and Ann TCCA, slightly positively correlated with Ann WSA, and slightly negatively correlated with Ann PWA and Ann TA.

PCA results (Figs. 2 and 3) showed that set 2 and 3 phenological events from beginning of flowering to beginning of fruit set (stages I1, I2 and J1) and from full veraison to harvest (stages M2 and O) were strongly positively with Ann TCCA and Ann TPA, slightly positively correlated with Ann WSA, and slightly negatively correlated with Ann PWA. In addition, the full fruit set (stage J2) and beginning of veraison (stage M1) were strongly positively correlated with Ann WSA, slightly correlated with Ann TPA and Ann TCCA, and strongly negatively correlated with Ann PWA.

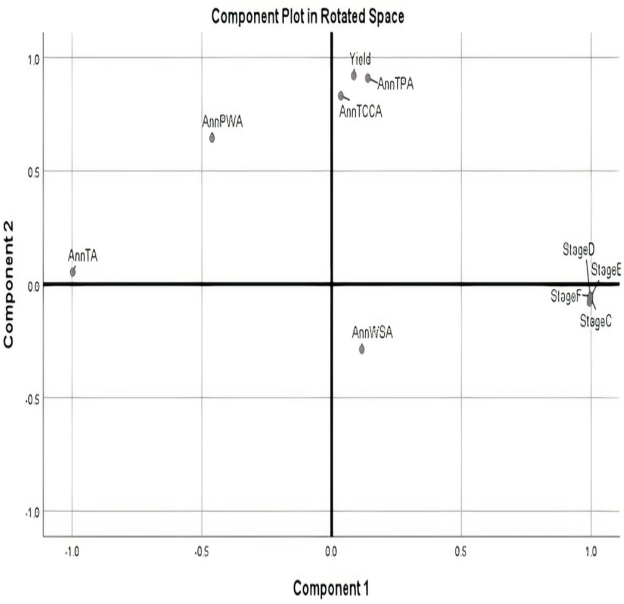

Fig. 1 : Correlation of White and Red Hassaoui grapevines set 1 phenological stages and yield with climatic factors (annual values during the last forty one years).

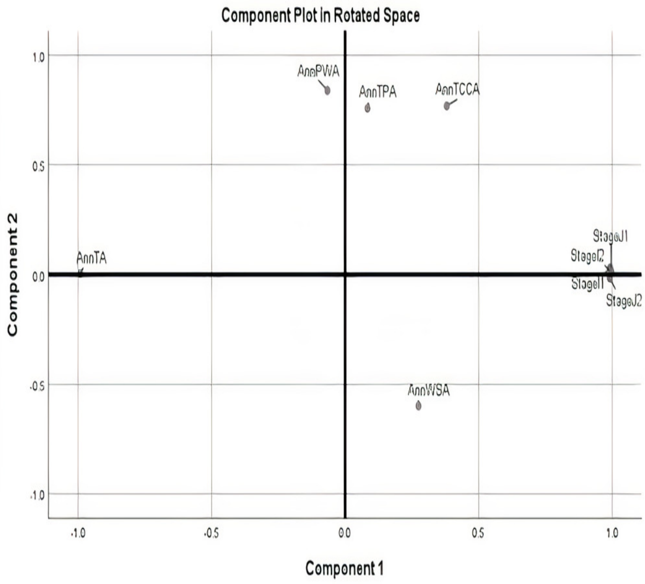

Fig. 2 : Correlation of White and Red Hassaoui grapevines set 2 phenological stages with climatic factors (annual values during the last forty one years).

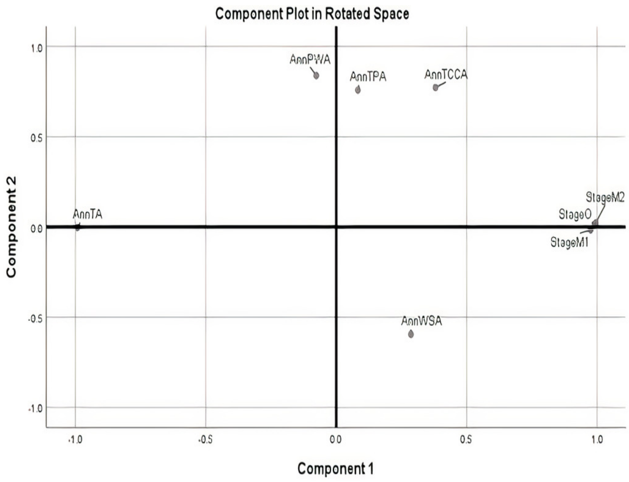

Fig. 3 : Correlation of White and Red Hassaoui grapevines set 3 phenological stages with climatic factors (annual values during the last forty one years).

PCA results (Fig. 4) showed that set 4 intervals of time from budburst to flowering (P1), budburst to fruit set (P2), budburst to veraison (P3), beginning of flowering to veraison (P4), and full flowering to veraison (P5) were strongly positively with Ann TA, Ann PWA and Ann WSA and slightly positively correlated with Ann TPA and Ann TCCA.

PCA results (Fig. 5) showed that set 5 intervals of time from beginning of veraison to full veraison (P6), beginning of veraison to harvest (P7), full veraison to harvest (P8), beginning of flowering to harvest (P9), full flowering to harvest (P10), and budburst to harvest (P11) were strongly positively correlated with Ann WSA and slightly positively correlated with Ann TPA, Ann TCCA and Ann PWA.

In the current study, the climate change exerted almost similar effect on the performance of both tested varieties. It was observed that the mean yield of White Hassaoui variety decreased between 1997 and 2019 in comparison with the mean yield noted between 1979 and 1996. Same trend was observed with Red Hassaoui variety. In all cases, White Hassaoui variety averagely yielded more than Red Hassaoui despite the occurring climate change. The relatively low decrease in yield of both varieties suggest their possible accommodation with climate warming as being the traditional and native grapevines of Al Ahsa.

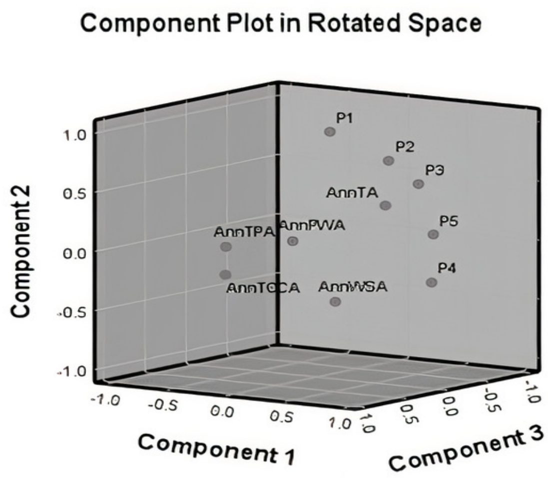

Fig. 4 : Correlation of White and Red Hassaoui grapevines set 4 intervals of time with climatic factors (annual values during the last forty one years).

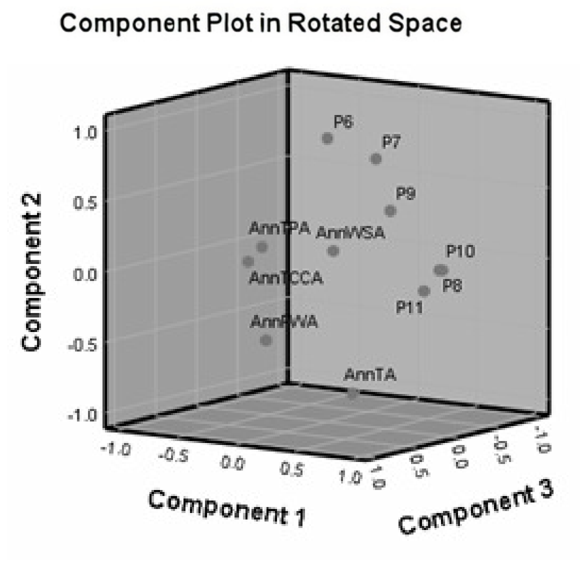

Fig. 5 : Correlation of White and Red Hassaoui grapevines set 5 intervals of time with climatic factors (annual values during the last forty one years).

Conclusion

During the last 41 years, the increase in temperature and decrease in precipitation were coupled with earlier phenological events, such as budburst, leaves unfolded, visible inflorescence, flowering, fruit set, and harvest. Positive effects resulted from climate change in terms of earliness of all phenological events of both White and Red Hassaoui varieties with a relatively low decrease in their yield. Farmers should take measures to reduce the light exposure that would be beneficial to maintain berry quality in Al-Ahsa region. In addition, the reducing total precipitation anomaly mainly in the last five years suggests the adoption of a drip irrigation system in Al Ahsa vineyards. This will overcome the low water availability for the grapevines in hot summers and reduce as much as possible soil's salinity that is one of the biggest problems facing Gulf countries, especially Saudi Arabia.

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